Response of Fuelbed Characteristics to Restoration Treatments in Piñon-Juniper-Encroached Shrublands on the Shivwits Plateau, Arizona

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***Abstract**—The recent encroachment of piñon (Pinus edulis) and juniper trees (Juniperus osteosperma) into historically shrub- and grass-dominated landscapes has caused major changes in ecosystem structure and function, including dramatic changes in fuel structure and fire regimes. Such encroachment is currently occurring on thousands of acres on the Shivwits Plateau in northwestern Arizona and land managers are seeking effective techniques to restore these areas to pre-invasion conditions and reduce the threat of high severity crown fires. A study was established on the Shivwits Plateau to test the effectiveness of three thinning techniques for reducing the density of recently established piñon and juniper trees and to assess changes to the fuelbed structure. The thinning treatments were: (1) cut and leave; (2) cut, buck and scatter; and (3) herbicide. The line-point intercept method was used to characterize changes in the fuelbed structure. Belt transects were used to quantify tree density. Responses of the shrubs and suffrutescent plants (herein collectively referred to as 'shrubs') are reported. Generally, there was more live shrub cover in the treatment units versus the control units. In addition, the mechanical treatments added woody fuels to the initially sparse sites. These two structural changes are expected to help to carry surface fire through the treated areas.*

Introduction

Tausch and others (1981) found evidence of expansion both in tree densities and geographical distribution of piñon-juniper (*Pinus* spp.- *Juniperus* spp.) woodlands over the last 175 years. The type conversion from shrubland to woodland leads to a decrease in understory plants such as shrubs, suffrutescent plants, bunchgrasses, and herbaceous species as the overstory canopy closes. This woodland expansion is a major concern for land managers due to the resulting loss of wildlife habitat associated with sagebrush steppe, decreased species diversity, loss of soil seedbanks, decreased aquifer recharge, increased soil erosion, and increased intensity of wildfires (Koniak and Everett 1982, Wilcox and Breshears 1994, Davenport and others 1998, West 1999, Miller and others 2000).

The range expansion of piñon and juniper is associated with increased fire return intervals due in large part to fire suppression and the reduction of surface fuels caused by the introduction of livestock grazing by European settlers (Miller and Rose 1999). In an attempt to return stands to pre settlement

In: Andrews, Patricia L.; Butler, Bret W., comps. 2006. Fuels Management—How to Measure Success: Conference Proceedings. 28-30 March 2006; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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conditions dominated by sagebrush steppe and shorter fire return intervals and to improve livestock forage and wildlife habitat, land managers have attempted to reintroduce fire and manipulate fuel conditions using mechanical, chemical, and seeding treatments.

Where woodlands are dense, shading inhibits herbaceous development, limiting the surface fuels necessary to support a low intensity surface fire. In this situation, fire does not propagate easily except under extreme fire weather conditions which typically results in undesirable intense overstory crown fires (Miller and others 2000). Where woodlands are more open and surface fuels still exist, managers can create low to moderate intensity surface fires with sporadic torching of larger trees, but even in these conditions fire can be difficult to propagate. For these reasons, sites have often been prepared before burning, typically by chaining landscapes to uproot trees and provide opportunities for early successional forbs, grasses, and shrubs to re-establish. However, chaining results in removal of both pre and post settlement trees and creates significant soil disturbance, which is not compatible with the management goals of many land management agencies, especially the National Park Service. As a result, mechanical thinning or chemical treatment of post settlement trees is becoming more common since such treatments create uneven-aged woodland stands which better represent historic conditions, provide better wildlife habitat, and do not create significant soil disturbance. Minimizing soil disturbance is especially important in areas where cultural resources may otherwise be at risk. By reducing overstory canopy cover, understory plants will have a chance to grow, increase cover, and create fine fuels that will support a lower intensity surface fire through the area.

To this end, this study on the Shivwits Plateau in northwestern Arizona was established to compare the effectiveness of two types of mechanical and one type of chemical thinning treatments as well as their costs for:

1. reducing densities of post-settlement piñon (*Pinus edulis*) and juniper (*Juniperus osteosperma*) trees;
2. increasing cover and seedbank density of native annual plants and perennial grasses;
3. increasing plant species diversity;
4. minimizing cover and seedbank density of invasive alien plants; and
5. creating a fuelbed that promotes the re-establishment of historic low to moderate intensity surface fires.

This report examines the first and fifth objectives.

Materials and Methods

Study Site

The study site (~405 ha/1,000 ac) is located within a single watershed on the northern rim of the Grand Canyon on the western Colorado plateau. The administrative boundaries of the project are within the National Park Service (NPS) portion of the Grand Canyon–Parashant National Monument, an area jointly managed with the Bureau of Land Management (BLM), Arizona Strip Field Office. The site is at 1,890 m (6,200 ft), with slopes from two to 15 percent. Mean annual precipitation is 33 to 43 cm (13 to 17 inches), bimodally distributed in summer monsoons from late June to early September, and winter frontal systems from November through March. Mean annual soil temperature is 9 to 13 °C (49 to 56 °F), and the frost-free period is 135 to 150 days.

European settlement of the area occurred in the mid 1800s and included extensive cattle grazing until the late 1980s when grazing was terminated on the site. Historic evidence of prolific cattle grazing remains in the study region including corrals, drift fences and earthen water tanks. Some of this region was chained in the late 1950s to early 1960s by a local rancher in an effort to improve range forage conditions. The area was "withdrawn land" by the Bureau of Reclamation in the 1930s and was transferred to the National Park Service in 1964.

Fire suppression has likely occurred concomitantly with European settlement. Organized fire fighting responsibilities have been shared by the BLM and NPS since the 1950s. A Prescribed Natural Fire Plan was implemented for the area in 1998 and fires are currently being managed as "wildland fire use" which is synonymous with allowing lightning-ignited fires to burn under certain management approved conditions.

Lightning storms commonly occur in the area throughout the monsoon season. There is evidence that moderately-sized fires burned historically in the area [up to 40 ha (100 ac)], but in the last 25 years smaller fires less than one hectare and single tree fires were more common. In an attempt to reintroduce low- to moderate-intensity surface fires, the NPS has implemented over 2,400 ha (6,000 ac) of prescribed fires in the area since the program started in 1994. Prescribed burn objectives were only met on approximately 600 ha (1,500 ac), which included the majority of the formerly chained areas. Most of the untreated/unchained areas did not carry fire with the use of a helitorch except under extreme fire weather conditions. Monitoring has shown that plant diversity has generally increased in burned areas; however, native grasses have only increased in small isolated areas, possibly due to a depleted soil seedbank. In order to help meet resource objectives, assessment of alternative treatments besides simply attempting to reintroduce fire appears to be necessary.

Current land management goals at this site are to preserve, restore, and maintain naturally functioning ecosystems and cultural resources. Other goals are to maximize native plant and animal diversity within the natural range of variation. Primary management concerns are related to soil erosion potential, and it is believed that current site conditions will not adequately sustain soil resources in the event of a high severity crown fire. The site is ideal to conduct restoration activities since cattle grazing has been excluded; no elk exist in the area; and deer, small mammals, and insects are the only remaining grazers. The lack of excessive grazing pressure should facilitate the re-establishment of native grasses, forbs, shrubs, and suffrutescent plants. The NPS Lake Mead Exotic Plant Management Team is available to control invasive plants in the event that they begin to appear in the study area.

Study Design

Thirty-two, 8.1 ha (20 ac) units were laid out and each unit was randomly assigned to be left untreated (control) or to have one of three thinning treatments applied. The treatments consisted of two types of mechanical and one chemical thinning treatment. The goal of all thinning treatments was an 80 percent reduction of post settlement trees. Land managers estimated that this level of tree reduction would open the stands enough to provide favorable establishment and growing conditions for perennial grasses and other vegetation, provide fuels to support a low to moderate intensity surface fire, and provide enough ground cover to reduce the potential for soil erosion. Post settlement trees were defined as those ranging in age from 1 to 175 years old (Class 1 to 3 trees; Bradshaw and Reveal 1943). None of the oldest trees (Class 4) were to be cut or sprayed. This classification of piñon and juniper trees was based on general guidelines such as diameter at stump height or breast height, tree height, and growth form.

The mechanical thinning options consisted of either a cut-leave or a cut-buck-scatter scenario. Trees were not marked prior to cutting, but rather the thinning crews were briefed on what factors constitute a post settlement tree and were given the direction to cut four post settlement trees and leave the fifth post settlement tree they encountered uncut. In this manner, an 80 percent reduction in tree density of each species should occur. In the cut-leave treatment, trees were cut with either loping shears or chainsaws and left where they fell. The cutting methods were the same in the cut-buck-scatter treatment, but the larger trees were then limbed to manageable lengths and the material scattered across the site, avoiding placing slash under the drip-lines of uncut trees. Approximately 20 percent of the mechanical thinning was accomplished by a National Park Service fire crew with the remainder completed by contract crews.

The herbicide thinning treatment used 15 percent Tordon 22K (DOW) that was batch mixed at 11.4 liters (three gallons) increments directly into SP-3 backpack sprayers at a rate of 709.8 milliliters (24 fluid ounces) of chemical to 3.78 liters (1 gallon) of water with 29.6 milliliters (one fluid ounce) of Blaze-on blue dye and one milliliter (0.03 fluid ounce) of kinetic nonionic surfactant. Since this method is a spot treatment, the rate applied per unit area is dependent upon the target tree density. For this treatment, the average application was 1.84 liters per hectare (25.15 ounces per acre) of Tordon 22K. The spray mixture was applied as a solid stream to the base of the tree at the soil interface (Williamson and Parker 1996). A 4.6 m (15 ft) buffer was left around each pre settlement tree encountered due to concerns for chemical drift in the soil. Other trees, regardless of their classification that fell in this zone, were not treated. It was estimated that these trees would constitute the 20 percent residual leave tree target; therefore, every post-settlement tree located outside the buffer zones was treated with herbicide. Herbicide application was performed by the Exotic Plant Management Team from Lake Mead Recreation Area.

No cutting or herbicide application was implemented in the control units. All treatments were completed prior to the start of our sampling.

Sampling

In each treatment unit, three plots were randomly located. At each plot, we laid out a 50 m (164 ft) line transect, which ran down the center of a 6x50 m (20x164 ft) belt transect. Vegetation data was collected along the 50 m line transect using the line-point intercept method (Lutes and others 2006) and tree data was collected within the belt transect. Plots were established in 2004 after completion of the thinning treatments and measured in late August/early September of 2004 and 2005.

Trees—Since cutting took place before plot establishment, we could not note the features such as tree height, growth form, or diameter at breast height or stump height of cut trees that Bradshaw and Reveal (1943) used for their classification system and that the thinning crew used when making the decision of which trees to cut. We used data from Miller and others (1981) to develop relationships between diameter at stump height, diameter at breast height, and groundline diameter (g.l.d.) and we assigned each of the trees/stumps in our data set a Class based solely on g.l.d. (table 1). Trees that were treated with herbicide were either labeled as dead or "sick." If, by appearance, they were unhealthy and expected to die in the near future they were deemed sick.

All trees/stumps located within the 6x50 m belt transect that had a g.l.d. of 7.6 cm (3 inches) or greater were recorded along with the species. This left the smallest Class 1 trees unmeasured, leading to the assumption that the Class 1 trees measured and those that were thinned were representative of smaller trees as well. Although other tree attributes were measured, density and percent reduction will be the only tree data presented in this paper.

Surface fuels—Along the 50 m (164 ft) line transect that bisected the belt transect, we sampled fuel groups by category (fine slash, coarse slash, fine woody debris, coarse woody debris, grass, live shrubs, dead shrubs, trees by species, forbs, and bare soil) using the line-point intercept sampling methods. The height of the tallest interception by fuel group was recorded at 0.5 m (1.6 ft) intervals. Since we did not sample prior to treatment establishment, the distinction between 'slash' and 'debris' was made in an attempt to determine woody fuel presence prior to and following treatment application. True shrubs such as scrub oak (*Quercus turbinella*), cliffrose (*Purshia mexicana*) and sagebrush (*Artemisia tridentate*) as well as suffrutescent plants such as broom snakeweed (*Gutierrezia sarothrae*) are combined in our 'live shrub' and 'dead shrub' categories. The fuel that will contribute to fire spread in this system is made up of plants such as shrubs and grasses as much as it is woody fuels; therefore, much of our focus was spent on assessing continuity of plant growth. Live shrub cover is the only surface fuel component that will be presented in this paper.

Data Analysis

For the line-point intercept method of cover determination, percent cover is calculated by summing the number of hits per line and dividing by 100. In our situation, we had 100 points per line, so it was a matter of simply summing the number of hits. For example, if forbs were encountered at 13 of the 100 points along a line, this computes to a 13 percent cover for forbs.

Table 1—Groundline diameter classes used to distinguish tree class for juniper and piñon trees. Breakpoint diameters based on Bradshaw and Reveal (1943) and Miller and others (1981).

	Diameter at groundline			
	Juniper		Piñon	
	- - cm - -	*- - in - -*	*- - cm - -*	*- - in - -*
Class 1	<10.2	<4	<8.9	<3.5
Class 2	10.2-24.1	4-9.5	8.9-21.8	3.5-8.6
Class 3	24.2-35.8	9.6-14.1	21.9-31.8	8.7-12.5
Class 4	>35.8	>14.1	>31.8	>12.5

We used general linear mixed models (GLMM) to examine differences in live shrub cover and pre treatment tree density between treatments (SAS Institute v.9.1, Littell and others 1996). All mixed models used a completely randomized design with subsampling and the Tukey-Kramer method to detect treatment differences.

Results

Live Tree Density

Prior to treatment, there were no statistical differences in density of either juniper ($F_{3,26}$ = 0.28; p = 0.84) or piñon ($F_{3,26}$ = 0.65; p = 0.59) between treatment types. Across all treatment units, there was an average of 508 juniper trees per hectare (t.p.h.) [206 trees per acre (t.p.a.)] and an average of 134 piñon t.p.h. (54 t.p.a.).

The cut-leave treatment reduced post settlement juniper trees by 83 percent and piñon by 77 percent. Of the pre settlement trees identified by our definition, 11 percent of the juniper and no piñon trees were cut (table 2).

Ninety-two percent of the post settlement juniper trees were cut in the cut-buck-scatter treatment, with 100 percent Class 1 juniper trees cut and 99 percent of Class 2 trees cut. Seven percent of the pre settlement juniper trees were also cut. Of the post settlement piñon trees identified, 64 percent were cut. None of the pre settlement piñon trees were cut (table 2).

Of the herbicide-treated juniper trees, 50 percent of the post settlement trees were dead three years after application with another18 percent designated as sick. Providing these trees die as a result of the treatment, the juniper trees will be reduced by 68 percent. Thirty-two percent of the pre settlement juniper trees were killed and another 11 percent were sick. Seventy percent of the post settlement piñon trees were dead in 2005 and seven percent were sick. Combined, this will result in a 77 percent reduction in post settlement piñon trees. There was only one pre settlement piñon tree identified and it was killed (table 2).

Table 2—Percent reductions of trees by treatment, species, and tree class. For the herbicide treatment, percent reductions based on dead as well as dead plus sick are included.

Treatment	Species	Class 1	Class 2	Class 3	Total Post Settlement	Class 4 (Pre Settlement)
		Percent reduction				
Cut-Leave	juniper	93	86	69	83	11
	piñon	82	84	25	77	0
Cut-Buck-Scatter	juniper	100	99	69	92	7
	piñon	89	65	18	64	0

Treatment	Species	Class 1 dead	Class 1 dead + sick	Class 2 dead	Class 2 dead + sick	Class 3 dead	Class 3 dead + sick	Total Post Settlement dead	Total Post Settlement dead + sick	Class 4 dead	Class 4 dead + sick
		Percent reduction									
Herbicide	juniper	53	73	49	64	49	75	50	68	32	43
	piñon	95	95	69	77	27	45	70	77	100	na

Live Shrub Cover

There were no significant differences in live shrub cover in 2004 ($F_{3,26}$ = 0.19; $p > 0.9$) (fig. 1). Cover in the areas treated with herbicide was highest with 5.5 percent cover. The cut-leave treatment had the lowest cover with 3.8 percent. Intermediate between the herbicide and cut-leave treatments were the cut-buck-scatter and control treatments, with 4.3 and 5.1 percent cover, respectively.

Cover increased in all treatments in 2005. Control units had 15 percent cover, cut-buck-scatter units had 27 percent cover, cut-leave units had 38 percent cover, and herbicide units had 36 percent cover. There were statistical differences in live shrub cover between treatments ($F_{3,26}$ = 12.29; $p < 0.0001$). Live shrub cover in the control units was significantly lower than the thinned treatments ($p < 0.05$); however, there were no differences between the thinned treatments (fig. 1).

Discussion

Live Tree Density

By only providing general growth form guidelines to the cutting crew, it most likely cost less per unit area to execute the treatments, but it also left more ambiguity and room for failure in meeting the treatment objective of 80 percent reduction in post settlement tree density. Depending on land management goals, the range of reduction in post settlement tree density that we captured

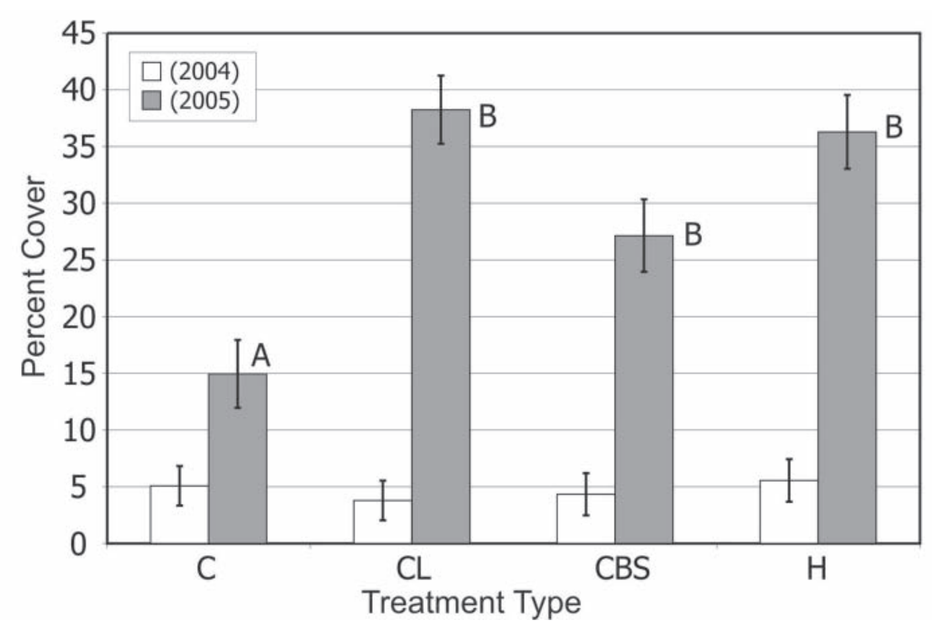

Figure 1—Percent live shrub cover for 2004 and 2005 by treatment type as measured using the line-point intercept method. There were no significant differences between types in 2004 ($F_{3,26}$ = 0.19; p = 0.9033). Uppercase letters (A, B) represent significant differences between types in 2005 ($F_{3,26}$ = 12.29; $p < 0.0001$). C = control; CL = cut-leave; CBS = cut-buck-scatter; and H = herbicide. Error bars represent one standard error about the mean.

(64 to 92 percent) may be acceptable. In addition, if pre settlement tree retention is only of low to moderate priority, then this method of determination for thinning is probably appropriate. If the goal of an 80 percent reduction in post settlement trees is an important target and retaining pre settlement trees is a high priority, it may well be worth the cost of better assessing tree ages by coring the largest trees and marking trees to be thinned or retained. Another option may be to thin trees based on a target tree density, rather than a percent reduction of a portion of current density based on tree diameter.

Based on our methods of assessment, it appears that the cut-leave thinning treatment produced results closest to the objective of 80 percent tree reduction (table 2). This may well be due to the relatively simple nature of this method. A cut tree provides an immediate measure by which to assess efficacy and, by not taking time to buck and scatter the larger trees, a more consistent flow can be kept by the thinning crew. Cutting was heavier in the smaller trees (Classes 1 and 2) in both of the cutting treatments, which may be an indication of the level of uncertainty in using general growth form as a cutting guideline.

The intricacies of the herbicide application, with care taken for soil drift, may have led to the low reductions in post settlement trees that we documented. Another consideration may be that crews were constrained by maximum allowable herbicide application per unit area.

Live Shrub Cover

Live shrubs responded favorably to the thinning treatments. In 2004, live shrub cover was second highest in the control units at 5.1 percent. In 2005, following a strong monsoon season, the cover of live shrubs in the control units nearly tripled to 15 percent. This threefold increase, however, was the lowest in 2005 and was dwarfed by the response seen in the treatment units. The cut-leave units underwent the greatest increase in live shrub cover with a tenfold increase, but were not distinguishable from the other thinned treatments. Live shrub cover in the cut-buck-scatter and herbicide units increased by roughly six times (fig. 1). Observationally, most of the increase in shrub cover came from broom snakeweed (Gutierrezia sarothrae); a suffrutescent plant which is an increaser on disturbed sites (U.S. Department of Agriculture, Forest Service 1937) and can help minimize soil erosion (Campbell and Bomberger 1934).

In summary, regardless of the accuracy of the thinning treatments relative to the goal of 80 percent post settlement tree reduction, thinning is apparently facilitating the creation of a fuelbed which should help to carry a surface fire through the area. The thinning treatments have opened the sites up, allowing an increase in live shrub cover as well as adding woody structure that should help to support a desirable surface fire and provide nurse sites for future plant germination and establishment. Dependant on funding, the next phase of this study will be to burn half of the units to determine the impacts of the thinning treatments on fire behavior and consequent fire effects.

Acknowledgments

We would like to thank the Joint Fire Sciences for funding this study (#03-3-3-58) and Duncan Lutes (SEM; Missoula, MT) for helping to develop our methods. In addition, Duncan Lutes and Mick Harrington of the Missoula Fire Lab greatly improved this paper with their reviews. Logistics support from Shirley Kodele, NPS and Tim Duck, BLM in St. George, UT has been invaluable.

References

Bradshaw, K. E.; Reveal, J. L. 1943. Tree classification of *Pinus monophylla* and *Juniperus utahensis.* Journal of Forestry:100-104.

Campbell, R. S.; Bomberger, E. H. 1934. The occurrence of Gutierrezia sarothrae on Bouteloua eriopoda ranges in southern New Mexico. Ecology. 15(1): 49-61.

Davenport, D. W.; Breshears, D. D.; Wilcox, B. P.; Allen, C. D. 1998. Viewpoint – sustainability of piñon-juniper ecosystems – a unifying perspective of soil erosion thresholds. Journal of Range Management. 51:229-238.

Koniak, S.; Everett, R. L. 1982. Seed reserves in soils of successional stages of piñon woodlands. The American Midland Naturalist. 108:295-303.

Littell, R. C.; Milliken, G. A.; Stroup, W. W.; Wolfinger, R. D. 1996. SAS system for mixed modesl. SAS Institute, Cary, N.C.

Lutes, D. C.; Keane, R.E.; Caratti, J. F.; Key, C. H.; Benson, N. C.; Sutherland, S.; Gangi, L. J. 2006. FIREMON: Fire effects monitoring and inventory system. General Technical Report RMRS-GTR-164-CD, USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO USA.

Miller, E. L.; Meeuwig, R. O.; Budy, J. D. 1981. Biomass of Singleleaf Pinion and Utah Juniper. INT-RP-273, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 18 p.

Miller, R. F; Rose, J. A. 1999. Fire history and western juniper encroachment in sagebrush steppe. Journal of Range Management. 52:550-559.

Miller, R. F.; Svejcar, T. J.; Rose, J. A. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management. 53:574-585.

Tausch, R. J.; West, N. E.; Nabi, A. A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34(4): 259-264.

U.S. Department of Agriculture, Forest Service. 1937. Range Plant Handbook. Washington, D.C. 532 p.

West, N. E. 1999. Juniper-pinyon savannas and woodlands of western North America. Pp. 288-308 in Anderson, R. C.; Fralish, J. S.; Baskin, J. M. (eds.) Savannas, barrens, and rock outcrop plant communities of North America. Cambridge University Press, London UK.

Wilcox, B. P.; Breshears, D. D. 1994. Hydrology and ecology of piñon-juniper woodlands: conceptual framework and field studies. Pp. 109-119 in Shaw, D. W.; Aldon, E. F.; LoSapiro, C. (eds.) Proceedings: desired future conditions for piñon-juniper ecosystems. GTR-RM-258, US Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Williamson, M.; Parker, D. April 1996. Low-Impact, Selective Herbicide Application For Control of Pinon/Juniper: A Field Guide. USDA, Forest Service, Southwestern Region.